BlueSkyRAINS West (BSRW) Demonstration Project

Final Report 2006

Implementation and evaluation of a wildfire and wildland fire use smoke modeling framework for the Western United States during the 2005 fire season

November 2006

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Executive Summary

The BlueSky wildland smoke modeling framework calculates emissions from fires, ingests computer forecasts of weather, and models the dispersion of smoke and the resulting ground-level concentrations of particulate matter. BlueSky has been linked to a geographic information system (GIS) display system called the **R**apid **A**ccess **IN**formation System (RAINS) to display smoke and geographical features.

From May through December 2005, an interagency demonstration project tested the ability of BlueSkyRAINS to model wildfire smoke in the Western United States. The test used fire information from the ICS-209 reporting system and a 12-km grid spacing for weather modeling. Funding for the BlueSkyRAINS West (BSRW) demonstration project was shared among the Environmental Protection Agency (EPA), Department of the Interior, and the USDA Forest Service. The major objectives were to (1) ensure that the BSRW system could operate reliably Westwide, (2) evaluate the performance of BSRW output against collected data, (3) assess how well BSRW output products met user needs, and (4) evaluate the potential of BlueSky for future national implementation.

In their review of the project, the interagency team concluded that although BlueSky is perhaps the best modeling framework available for wildland fire smoke particulates, it is still a research tool and needs both further development to improve the accuracy of its predictions and further testing before it can be considered operational. Although significant development work is needed, investments already made in the BlueSky framework are paying off and additional work is justified.

As far as technical performance, smoke predictions are difficult to evaluate in the field without significant resources (e.g., money, equipment, and people) and planning of field trials. In general, users appeared to support the need for a smoke modeling system, such as BlueSky, and liked the fire weather information produced ancillary to the smoke predictions. Only a few users considered themselves expert on the GIS-based RAINS display system, resulting in limited adoption in part because of the system's complexity. Time and effort are needed to develop a Westwide or national user community for BlueSkyRAINS through increased research, training, and outreach. Further technical improvements will be needed to build users' confidence in the accuracy of the system.

Recommendations from the BSRW demonstration project are to:

- Develop methods and data systems that will facilitate accurate wildland fire activity information to support smoke modeling for assessing impacts to air quality.
- Improve BlueSky accuracy of modeled trajectory and fine particulate concentrations to encourage user confidence.
- Continue development of the BlueSky modeling framework at the Fire Consortia for the Advanced Modeling of Meteorology and Smoke (FCAMMS), implementing it region by region (i.e., no national or continued Westwide implementation at this time) with the goal of improving the tool.
- Improve RAINS or develop alternate approaches to give users more display choices.
- If BlueSky is funded and developed as a national interagency tool, institute a formal, national, interagency advisory and coordination committee.
- Improve understanding and national acceptance of the system, so it can eventually be a candidate for use in air quality planning by EPA and the States as an operational tool.

Contents

1. Introduction

BlueSkyRAINS is a decision-support tool that predicts smoke impacts from wildland fire (wildfire, wild land fire use, prescribed fire) and delivers these forecasts to managers through the Web. Like any complex computer-automated decision-support system, BlueSkyRAINS must have data and infrastructure to support its operation. In this case, the tool requires significant fire activity data and supercomputer resources to operate, and expertise to produce meaningful assessments of products.

In 2004, Environmental Protection Agency (EPA) Administrator Mike Leavitt was given a demonstration of BlueSkyRAINS, and was so impressed that he subsequently tasked the EPA with investigating the feasibility of implementing BlueSkyRAINS for the 2005 fire season across all Western States for wildfires. The result was the multiagency 2005 BlueSkyRAINS West (BSRW) demonstration project. The project developed a new partnership among the USDA Forest Service Pacific Northwest (PNW), Rocky Mountain, Pacific Southwest, and Southern Research Stations; Forest Service National Forest Systems and State and Private Forestry, EPA; and the Department of the Interior.

This report describes the BSRW demonstration project, its findings, and resultant recommendations. BlueSkyRAINS was used to predict smoke impacts from wildfires and wildfire use fires from the ICS-209 reports over the 11 Western States during the 2005 fire season. The project objectives were to:

- Determine whether the system could operate reliably over such a large territory (i.e., the Western States).
- Conduct a limited evaluation of BlueSky performance.
- Survey users of the BSRW demonstration products to assess usability and future needs.
- Assess the potential for future BlueSky development and national implementation.

2. BlueSkyRAINS: Background

2.1. What is BlueSkyRAINS and why was it developed?

BlueSky is a smoke modeling framework that predicts smoke concentrations expected from burning activities. The geographic information system (GIS)-based Rapid Access Information System (RAINS) is a visualization tool that maps BlueSky predictions of smoke trajectories and particulate concentrations and makes them available in a user customizable interface through the Web. Together, the tools form a complete system for creating and delivering smoke predictions for use in decision support.

Wildland fire smoke can contribute to exceedances of the Clean Air Act National Ambient Air Quality Standards and to impairment of visibility through regional haze. Also, public tolerance of smoke has diminished over time, and complaints are frequently received about smoke impacts from prescribed burning, wildland fire use fires, and wildfires. Several lawsuits have affected regional prescribed burning programs, and some regions now include potential wildland fire use and wildfire smoke impacts when considering management options.

The ability to predict smoke impacts enables managers to understand consequences of their actions and communicate better information to regulators, local officials, and the public. Systems for smoke dispersion modeling can also help managers focus their tactics and fire management resources to control and minimize adverse effects from smoke.

Land managers, fire managers, air quality regulators, and others need information about potential smoke impacts. For example:

1. What is the maximum smoke concentration that could be expected downwind in areas of concern?
2. When is the smoke likely to arrive at a location?
3. Where will smoke most likely impact visibility?
4. Will the National Ambient Air Quality Standards be exceeded?
5. What roads are at greatest risk from smoke incursion?
6. Where should public health alerts be issued?
7. What potential actions might be taken (or avoided) to mitigate smoke impacts?

The BlueSky smoke modeling framework is designed to help answer such questions by providing projections of smoke concentrations.

2.2 How does BlueSkyRAINS work?

BlueSkyRAINS combines computer-generated terrain, grid-based weather forecasts, and fire activity information to create predictions of smoke concentrations from fires. The results are then made available through the Web, including a Web-based GIS interface.

BlueSkyRAINS combines two components:

1. **The BlueSky smoke modeling framework.**
   The BlueSky smoke modeling framework provides real-time predictions of smoke from approved or planned prescribed fires and wildfires. It couples state-of-the-science weather, fuels, consumption, emissions, and dispersion models in a modular framework in order to produce these real-time predictions. By gathering and using information on all fire activity in a region, BlueSky not only predicts the smoke impacts from a single fire, but also predicts cumulative impacts from multiple fires. BlueSky cannot be separated from highly complex weather models (generally either the MM5 or WRF models, which run on supercomputers), as it is totally dependent on this input to develop smoke simulations. BlueSky was designed to be modular and portable in order to facilitate development and implementation.
2. **The Rapid Access Information System visualization system.**
   The RAINS visualization system is an interactive way to view GIS through the Web. Users can control the specific data layers shown, zoom in on their region of interest, and obtain quantitative answers to specific data queries. For BlueSkyRAINS, the RAINS visualization system has been customized to function with output from the BlueSky framework.

Each component (BlueSky and RAINS) can function independently, because of the modular design. BlueSky and RAINS are both open-sourced and available for community development. Both, however, require system hardware that is beyond the capabilities of high-capability personal computers or single-processor workstations.

2.3 What are the uses of BlueSky smoke predictions?

BlueSky was originally developed to assist land managers with prescribed burning decisions. However, BlueSky is a unique source of information, and as such, it has potential applications in many areas of land, fire, and resource management that are concerned with smoke (table 1). These applications include prescribed burning, wildland fire use, and wildfires. Managers can use the BlueSky smoke predictions not only for go/no-go decisions, but also for public safety notification, regulatory oversight, and scientific knowledge.

Table 1—Potential uses and users of BlueSky (indicated by filled in boxes)

Potential uses and users of BlueSky	Fire Types			Users								
	Rx	WFU	Wildfire	Fire Mgrs	GACC	IMT	Regulators	Air agencies	Health agencies	Local officials	Public	Researchers
Decisionmaking support (e.g., go/no-go, WFU classification)	■	■		■				■				
Firefighting (FF) tactics (e.g., effects of burnouts)		■	■	■		■		■	■			
FF resource deployment (e.g., aviation)		■	■		■	■						
Improved knowledge about emissions, climate	■	■	■				■	■				■
Location of air quality monitors	■	■	■	■			■	■			■	■
Public safety/transportation	■	■	■							■		
Single and multiple fire impacts (health/nuisance/visibility)	■	■	■	■	■		■	■	■	■	■	■
Notify public (health/nuisance/visibility)	■	■	■	■	■		■	■	■	■	■	
Regulatory – emission inventory/ apportionment/background	■	■	■				■	■				■
After action assessments and evaluations, exceptional event analysis	■	■	■	■			■	■				

GACC – Geographic Area Coordination Center.

IMT – Incident Management Team.

Rx – prescribed burning.

WFU – wildland fire use.

2.4. Where is BlueSkyRAINS available right now?

BlueSky smoke predictions are currently available throughout the coterminous 48 States through the Fire Consortia for the Advanced Modeling of Meteorology and Smoke (FCAMMS) (see figure 1). The FCAMMS are cooperative centers developed under the National Fire Plan for leading the development and application of advanced fire weather, fire research, and smoke management tools.

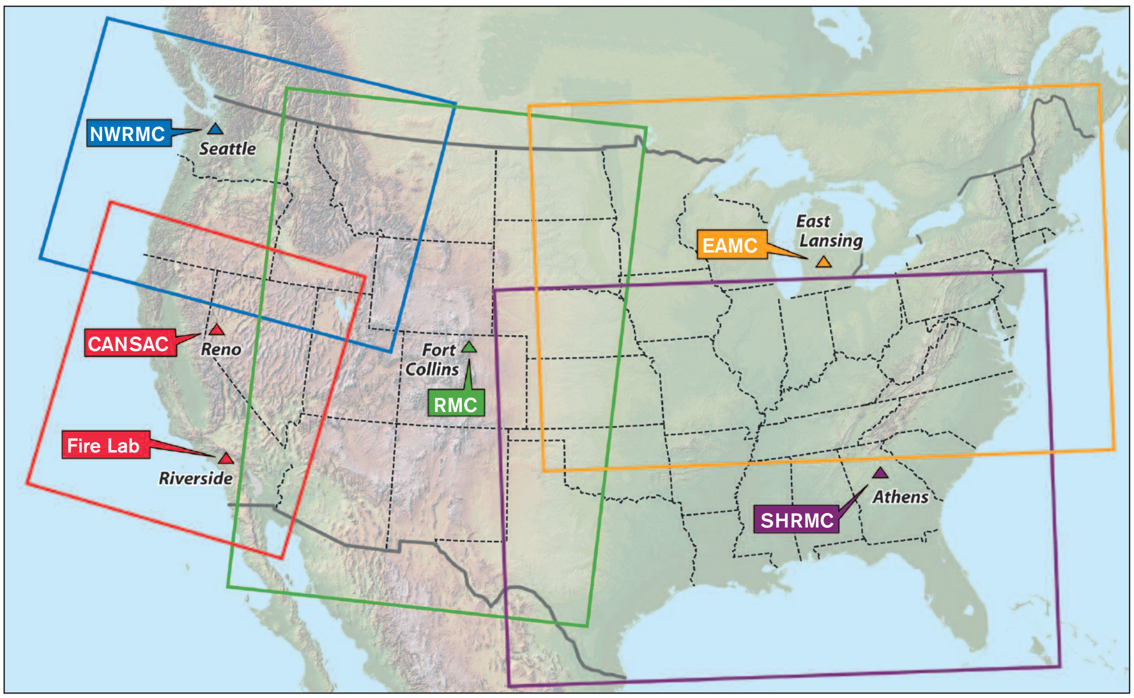

Figure 1—Coterminous United States, with Fire Consortia for the Advanced Modeling of Meteorology and Smoke (FCAMMS) modeling domains.

FCAMMS	
CANSAC	California and Nevada Smoke and Air Committee (Reno, Nevada and Riverside, California)
EAMC	Eastern Area Modeling Consortium (East Lansing, Michigan)
NWRMC	Northwest Regional Modeling Consortium (Seattle, Washington)
RMC	Rocky Mountain Center (Fort Collins, Colorado)
SHRMC	Southern High Resolution Modeling Consortium (Athens, Georgia)
Fire lab	Riverside, California

The RAINS interface is currently available only for the Pacific Northwest and Westwide implementations, but plans exist for RAINS or a similar interface to be available throughout the coterminous United States within the next year. Because of regional differences in the availability of fire information and weather predictions, the implementation of BlueSkyRAINS has necessarily differed somewhat by region (table 2).

Table 2—Implementation locations

Domain	Resolution	Forecast Period	FCAMMS	Forest Service Research Station	Wildfire	Rx fire	Ag fire	RAINS	In operation since
Northwest	12 km 4 km	72 hrs 48 hrs	NWRMC	PNW	X X	X X	X X	X X	2002
California / Nevada	4 km	48 hrs	CANSAC	PSW	X	M	—	*	2004
Northeast	12 km	48 hrs	EAMC	NRS	X	M	—	*	2004
Rocky Mountain	12 km 8 km	48 hrs	RMC	RMRS	X X	M M	— —	* *	2004
Southeast	12 km	48 hrs	SHRMC	SRS	X	M	—	*	2006
West (demo)	36 km 12 km	48 hrs	NWRMC/ RMC	RMRS/ PNW	X X	M M	— —	X X	Operated in 2005

Ag fire = agricultural fire.
Rx fire = prescribed burning.
X = in operation.
M = manual only.
— = not yet available.
* = implementation of RAINS is in progress as of June, 2006.
FCAMMS = Fire Consortia for the Advanced Modeling of Meteorology and Smoke.
PNW = Pacific Northwest Research Station
PSW = Pacific Southwest Research Station
NRS = Northern Research Station
RMRS = Rocky Mountain Research Station
SRS = Southern Research Station

The BlueSky system requires two inputs: daily numeric weather predictions from a weather model (e.g., MM5), and fire locations and sizes. The availability of these two inputs determines where the BlueSky system can be implemented. Specifically, the weather forecast model's area covered (domain), resolution, and forecast period define those parameters for the BlueSky predictions. Also, the fire information available (location, size, fuel type, fuel loading, etc.) determines what smoke sources are included in the smoke predictions.

Currently, BlueSky has been implemented for seven domains (table 2) covering the coterminous United States, through the FCAMMS. Several of the BlueSky domains are run at multiple resolutions.

All of the BlueSky domains include information from ICS-209 reports (taken from the national computer database) to supply wildfire location and size. The ICS-209 reports are daily updates on active, large, wildfires and wildland fire use. The reporting of prescribed fires and agricultural burns differs among the domains owing to variations in state requirements, and as a result, not all BlueSky domains have information available on these smoke sources.

The Northwest BlueSky implementation is connected to a RAINS server, which yields GIS-based, interactive maps. Other current BlueSky implementations are not yet connected to a RAINS server. However, the FCAMMS are developing a RAINS interface that should be available at all locations for the 2007 wildfire season.

2.5. Development and Funding History of BlueSkyRAINS

The BlueSky project was started in response to public concerns about smoke from prescribed burning in the Pacific Northwest. Researchers at the USDA Forest Service, Washington State Department of Ecology, and EPA Region 10 did preliminary feasibility studies in 1999. In fiscal year 2000, funding was received through the National Fire Plan, and the USDA Forest Service PNW Research Station's AirFire Team developed the BlueSky smoke modeling framework. The initial BlueSky prototype was implemented in the Pacific Northwest, because this region had numeric weather predictions and computerized prescribed fire activity information already available through local systems. In 2001, the first smoke predictions were made available for the Northwest domain through crude graphical displays. A consortium was created to allow a wide variety of federal, state, and local agencies and tribes help in shaping the BlueSky system.

The RAINS Web interface was originally developed by EPA Region 10. In 2002, PNW Research Station formalized a partnership with the EPA Region 10 to develop a version of RAINS that could be used with BlueSky.

By 2003, after preliminary tests in the Pacific Northwest, BlueSky was made available to all Forest Service research stations through the FCAMMS for collaborative development and evaluation. In 2006, BlueSky predictions became available throughout the coterminous United States. Implementation has been slower for the RAINS display, but RAINS should be available at all FCAMMS for the 2007 wildfire season.

To date, BlueSky development has been funded primarily by the National Fire Plan ($2.2 million), with additional development, training, and evaluation funded by the Joint Fire Science Program ($0.7 million) and Forest Service ($0.7 million), for a total investment of $3.6 million over 5 years. The development of RAINS to date has been funded primarily by the EPA. In 2005, the Forest Service, EPA, and Department of the Interior contributed a total of $0.8 million to fund the BlueSkyRAINS West 2005 demonstration project.

3. BlueSkyRAINS West 2005 Demonstration Project

3.1. Description of the 2005 Demonstration Project

During 2005, the BSRW demonstration project was conducted in the Western United States, to test the use of the BlueSkyRAINS framework for wildfires. The project area was the entire contiguous Western United States, and included the states of Washington, Oregon, California, Idaho, Nevada, Montana, Wyoming, Utah, Colorado, Arizona, and New Mexico (figure 2). Implementation was carried out by the USDA Forest Service's PNW and Rocky Mountain Research Stations and the EPA.

Figure 2—BSRW 2005 demonstration project area.

The project team set up the BlueSky smoke modeling framework to be run at Rocky Mountain Center (RMC) on its supercomputers for 12-km weather model resolution for the BlueSky output fields. The visualization system, RAINS, was implemented by EPA at Research Triangle Park, North Carolina. The PNW Research Station's AirFIRE team provided expert help and technical guidance for this large project.

For daily weather inputs, the project used predictions from MM5, a weather model that produced forecasts on a 12-km grid spacing 48 hours into the future, updated twice daily. For fire inputs, the project used automated input of wildfire and wildland fire use data from the national ICS-209 reports, and then used a simple fire growth algorithm to project this into the future. The national Fuel Characteristic Classification System (FCCS) fuel loadings were used as default values. The Consume and Emissions Production Models were used to calculate fuels consumed and resulting emissions.

By mid-April, the weather forecasts and the entire BlueSky framework were operating at RMC as planned, producing 48-hour forecasts at 0600 and 1800 daily in Coordinated Universal Time (UTC) zone. BlueSky operated continuously through December, 2005. Users who wanted additional information about prescribed fire smoke could manually enter prescribed fires into the system and, working with project staff, obtain simulations of the smoke from these prescribed fires along with wildfire smoke simulations. In one instance, a large burnout operation was simulated for the Cave Creek Wildfire in Arizona. After implementation, the major ongoing tasks were daily maintenance, quality control, and data archiving.

Implementation of the RAINS system was delayed because of contracting complications and was online in late August. Visual display of the BlueSky products was limited to static and animated files until the RAINS system was operational. Both the BlueSky and RAINS components were modified throughout the project to fix problems and make the systems more robust.

Field studies were conducted for two large fires during the 2005 season. The first, June 27-July 4, was the Black Range Complex, a wildland fire use incident on the Gila National Forest in New Mexico. The second was the Frank Church Fire Complex and Salmon-Selway Complex, from September 3-14, on the Salmon-Challis National Forest in Idaho.

The BSRW modeling system was operational through December 2005. In the winter and spring months of 2006, the partners involved in the BSRW demonstration project evaluated the project. Their findings and recommendations are in part 4 of this report.

3.2. Evaluation and Performance Criteria

The BSRW 2005 demonstration project was evaluated based on:

1. The accuracy of the BlueSky ground-level smoke concentrations and trajectory information.
2. The usability of the output information as displayed to users.

For these purposes, data were collected from cooperative field experiments, ongoing monitoring, satellite observations, and user surveys and interviews. The field data, monitoring data, and satellite observations were used to determine the performance of the model predictions on a technical quality and confidence-level basis. The user surveys and interviews were used to determine the applicability of the forecasts for decision management, including the appropriateness of the time and space scales, the availability and timeliness of the predictions, and the ease of use and understandability of their display.

4. Findings and Recommendations

The BSRW demonstration project was designed to answer four specific questions:

1. **Operations and reliability.** Could BlueSkyRAINS operate reliably for a Westwide domain?
2. **Model performance and evaluation.** What is the performance level of the BSRW output products?
3. **User needs.** Do BSRW products meet the needs of the interagency fire and air quality management communities?
4. **Future growth.** What issues remain for implementation of BSR on a larger scale, including nationally?

The BSRW demonstration project was of limited duration and scope, as well as very rapid implementation, and the answers to these questions are qualified by those facts. Within these limitations, the BSRW partners have developed findings and recommendations, given below.

4.1. Operations and Reliability

Finding:

- **BlueSkyRAINS can be operated Westwide successfully, within limitations.**

  BlueSky was successfully installed and operated for the full period of the project. After implementation in August, RAINS operated successfully for the remainder of the project.

  However, implementation of the system required considerably more effort than the team had anticipated, including staffing and funds. Computers had to be upgraded to handle the extended domains. A number of software problems were discovered, diagnosed, and corrected. Daily oversight of the system also took some significant time and personnel resources.

Recommendations:

- **Produce an operational version of BlueSky by the 2008 wildfire season.**

  The desired outcome would be a system that is able to operate reliably on a daily basis for the entire United States with minimal human oversight. We recommend that such a system be run regionally by the FCAMMS while being implemented in a consistent way nationally. Deployment would provide valuable information for Alaska, where there are substantial smoke issues.

  Although the BSRW demonstration project showed the conceptual validity and usefulness of this system, considerable development is needed before the system is ready for operational use. Important development steps include a complete software review at the code level, including modifications to the BlueSky and RAINS (or other visualization tools) to make the system more portable, reliable, and efficient.

  The BlueSky system is extremely complex compared to many operational fire management applications and relies on meteorological inputs. The complexity may mean that continuing development and refinement will be needed even after the system becomes operational. This situation is a common practice for air quality models applied to industrial sources and thus is not unique.

  We also recommend giving the current BlueSky system an interim status as an experimental wildland fire application that would encourage the training of users and use of the tool. Training, outreach, and technology transfer work are important.

- **Provide sufficient resources for further development of BlueSky, including equipment, personnel, and stable, multiyear funding.**

  Current development efforts are not as focused as they could be, owing to BlueSky development being funded through a number of small grants, limited National Fire Plan funds, and uncertain research base funding. A proposeal that rationalizes funding, with enough resources for development and ongoing research, will enable further refinement and improved use. An important consideration is streamlining information resource management processes for maintenance and upgrades to the necessary computer systems.

4.2. Model Performance and Evaluation

Findings:

- **The BlueSky modeling framework is useful.**
  BlueSky is a useful tool to integrate fire occurrence, fuels, and meteorological data from multiple fires to calculate emissions, trajectories, and concentrations. Because of its integrative capabilities, BlueSky can and likely will become a very important tool for smoke and air quality management.
- **Although model performance is currently limited, it can be improved.**
  During the field experiments, model performance was limited; improvement is needed. As with most air quality model applications, the reliability of the BlueSky estimates is diminished in rough terrain, for shorter periods, in finer spatial resolution, in closer distances to fires, and for predictions several days into the future.

  Although some prediction error will always be present, several configuration and model choice problems were identified in the BSRW implementation that have known solutions. Solving these problems offers a straightforward path to improve model performance, and better performance will improve user trust. Specifics are discussed in the recommendations section below.
- **The current version of BlueSky is not yet mature enough for deployment as a fully endorsed product for fire management application.**
  The model performance does not warrant deployment as a fully functional system at this time. Also, because BlueSky is very complex and relies on supercomputer technology, considerable work is needed to educate users about interpreting the results and understanding that some uncertainty is inherent with complex models. User education will be needed before implementing BlueSky or any other smoke modeling system as a national operational system.

Recommendations:

- **Implement known solutions to technical problems.**
  Specifically, the model boundary layer height showed an unrealistic collapse, which caused a spike in ground smoke concentrations daily at around 2000 to 2100 local time; this problem can be fixed through alternate methods of ingesting the model boundary layer height into the dispersion model. BlueSky will perform better when the out-of-date fire emissions model (EPM) is replaced by one that includes smoldering fuels (e.g., fire emission production simulator, or FEPS) and consumption of live fuels. Another improvement would be changing the settings on the MM5 weather prediction model to those used in air quality regulatory work. In the Northwest domain, a new scheme for calculating carry-over smoke from one day to the next improved BlueSky's performance during the Frank Church field experiment; making this same modification in all BlueSky implementations would likely improve performance. After all these fixes are in place, futher analyses could be done to check model performance.

- **Incorporate additional off-the-shelf technical features and new research developments into BlueSky.**

  Satellites provide a potentially useful, but largely untapped, resource for model evaluation, smoke tracking, and fire detection. In particular, incorporating data from satellite fire detection, satellite-observed smoke plumes, and satellite aerosol optical depth, will complement ground-based reporting and air monitoring. This can be accomplished within existing National Aeronautics and Space Administration (NASA) grant agreements.

  Examination of plume rise calculations would help determine the best method of setting the level of the smoke plume. A setting too high or too low causes the model to calculate smoke movement using the wrong wind layer. A new plume-rise model is being developed at the USDA Forest Service Southern Research Station, and it will be tested for improving BlueSky.

  Examination of fire growth models (e.g., FARSITE or FIRETEC), would help determine how best to predict fire size growth. The current method of estimation from existing fire size on the ICS-209 wildfire report is rudimentary at best. Current models do not adequately address the large burnouts that are common on wildfires.

  The use of new research on these and other fronts, as it becomes available, would improve BlueSky.

- **Clearly label BlueSkyRAINS as an interim experimental product while striving to improve it using known science and results of ongoing research.**

  Although more research and development is needed, the current system is still useful and can be run reliably. Model development will be benefited by allowing users in all the FCAMMS to become familiar with it and provide feedback to researchers. An interim approval by the Northwest Coordinating Group Fire Environment Working Team is needed for the BlueSky RAINS model. The interim approval will recognize the utility of BlueSkyRAINS and the need it potentially fulfills, while at the same time allowing fire managers time for thoughtful evaluation and suggested improvements.

Finding:

- **Fire size and location reporting systems are not complete, fully reliable, nor accurate.**

  The ICS-209 reporting system for wildfires and wildland fire use is not fully reliable in terms of fire size and location. Comparison of the ICS-209 wildfire report data with National Oceanic & Atmospheric Administration (NOAA) satellite fire detections showed significant discrepancies. Anecdotal concerns were also heard about the ICS-209 wildfire report completeness and timeliness. Because BlueSky depends on these reports to identify and characterize wildfires and wildland fire use, such concerns are pivotal. Prescribed fire reporting systems differ considerably over the BSRW area, thus providing skewed or inaccurate input.

Recommendation:

- **Improve the adequacy of daily fire activity data so the BlueSky framework will have accurate input data.**

  In the near term, improving wildfire activity data will include emphasizing the need for accuracy and timeliness of the ICS-209 reports. For the longer term, systems and methods are needed that improve the timeliness and quality of both wild and prescribed fire occurrence data. If such data can be stored in a database that is easily accessed by smoke and air quality management staff and ingested into BlueSky, the potential of the model could be realized. The quality and timeliness of the fire activity input data directly affect the ability of the BlueSky framework to provide reliable smoke forecasts. Such a database would be necessary to run either BlueSky or any other smoke modeling system successfully. Because of the implications of the new regulations for regional haze and particulate matter in the 2.5-micron size class (PM 2.5), the need for accurate information on wildland fire location, size, intensity, and fuel consumed is potentially a critical need within the next several years.

Finding:

- **Field experiments for air quality model validation are challenging, and multiple experiments are needed to accurately assess any model.**

  Field experiments for air quality model validation are technically difficult and expensive. Validating an air quality model requires many field experiments as each experiment is only one possible realization of the model-observation comparison that is biased by the prevailing conditions at the time. The BlueSky modeling framework cannot be fully evaluated by one (or even several) field tests, because each test can only address a small portion of the variability in fuels, fuel loading, meteorology, heat release, and terrain that may be encountered.

Recommendation:

- **Develop an approach to continue testing, evaluating, and validating performance.**

  We recommend initiating a combination of real-time validation from monitoring data, expansion of ambient monitoring capabilities for prescribed and wildfires, quantitative testing of model results against existing observational data sets, and specialized field experiments. This approach may be possible through the Joint Fire Sciences Program. To be done correctly by using all the methods above, this work would require several million dollars, and thus full funding would likely require leveraging competitive grant or special project funds with agency base funding.

4.3. User Needs

Finding:

- **A significant and continuing effort will be needed to conduct a more complete user needs assessment for BlueSkyRAINS.**

  This finding is based on 30 responses to a voluntary Web-based questionnaire (at the RMC FCAMMS), 14 telephone interviews, and additional information from ongoing, multiyear, user needs assessment activities by the Pacific Northwest's active user community. The results are preliminary and do not meet official U.S. Department of the Interior or USDA guidelines for user requirements assessments for life cycle management of software systems. Although we contacted a sample of knowledgeable people from most of the Western States to determine how they used the BlueSkyRAINS system, we recommend a more thorough assessment of user needs be completed.

Recommendation:

- **Develop an ongoing user needs assessment group for BlueSky at a broader level than the Pacific Northwest.**
  Include in the user needs group interagency members knowledgeable about wildland fire, smoke management, and air quality, and follow official procedures for life cycle management of computer applications.

Findings:

- **During the demonstration project, use of BSRW output products was limited.**
  The limited use occurred for a number of reasons. First, few people in the field knew that the BSRW system was available for access. Also, the system was only in operation for wildfires reporting ICS-209 data, a class of fires that are not assessed for violations under the National Ambient Air Quality Standards. Additionally, the RAINS interface for BSRW was not available until August. Finally, users in the Pacific Northwest had no incentive to switch to the Westwide demonstration because the existing Northwest system was run simultaneously and was available for prescribed, wild, and wildland fire use during the entire fire season. There has been limited BlueSkyRAINS training outside of the Northwest, which limits use and user capability.

- **User understanding of the system was limited.**
  Some potential users did not know about or have confidence in the accuracy of the predictions. A significant issue is the limited outreach about BlueSkyRAINS outside the Northwest and opportunities for training on the system prior to the study. There was no standardized class-room segment for the National Wildfire Coordinating Group RX-410 Smoke Management Techniques course that covered BlueSkyRAINS with any depth. A few potential users were blocked by administrative barriers because BlueSky is not an officially approved fire management application. Some of the users interviewed did not have the information they needed to develop a good understanding of how BlueSky can be useful, including an understanding of the relation between air quality regulations and smoke. Some individuals interviewed reported that BlueSky predictions are difficult for routine users to interpret, and data on the RMC Web site are presented in too complex a manner. Those individuals contacted who had reviewed the RAINS addition to BlueSky believe it is a valuable addition to the system, but several suggested it is also too complex. They suggested methods that might simplify or personalize RAINS.

- **Some users would like the system to be tailored to local user needs.**
  Some of the users interviewed stated that requirements differ regionally and are based on regulatory and program needs. Examples included highlighting accuracy in the near-field (less than 300 km from the fire). The differing requirements may point to a need to continue the regionalized deployment of BlueSky.

Recommendation:

- **Strive to build a larger BlueSky user community.**
  Provide user guidance on the uncertainty levels in BlueSky's predictions. Modify the framework to make allowances for local needs in the timing of projections. Localize BlueSky implementations in consultation with users to allow for regional differences; these localized versions would be in addition to a nationally consistent system (e.g., within the FCAMMS or other structure). Finally, we recommend building awareness and understanding of BlueSky capabilities and products throughout the potential user community including its current state as an experimental tool. A standard training lesson has been developed for BSR and can be used in all smoke management training courses where applicable. If other display systems are developed further, they could be supported with lesson plans also.

4.4. Future Growth

Findings:

- **BlueSky shows promise, but it is not ready to be adopted as an officially accepted fire management application nationally.**
  The complex BlueSky system and its output need to be carefully evaluated by scientists, air quality regulators, and fire managers before national centralized implementation. Accurately represent the research state of the current BlueSky products where needed so as to not build false expectations in operational readiness or accuracy of predictions. Premature implementation could detrimentally affect any future smoke modeling activities.
- **In our past interactions with managers and users, we have found that the initial reaction to BlueSkyRAINS is often extremely positive and enthusiastic.**
  BlueSkyRAINS provides unique information and an interactive graphics system. People's reactions to BlueSkyRAINS are generally positive as they begin to realize the full potential of the system. Because the BlueSkyRAINS graphics are colorful and compelling, there is naturally a ground swell of people who want the system to be immediately available but who are not aware of the scientific, technical, legal, and administrative implications of smoke simulation systems. BlueSky is unlike other wildland fire management applications in its complexity, need for advanced computing hardware, and the need for high levels of technical expertise to run the framework.

- **BlueSky is unlike other wildland fire management applications in its complexity, need for advanced computing hardware, and the need for high levels of technical expertise to run the framework.**

  Because BlueSky products can be viewed quickly on the Web, display results with little or no data input from users, and be accessed from almost any location, potential users can easily make the mistaken assumption that BlueSky is a simple model. This perception has perhaps led to a situation in which the resources devoted to BlueSky and RAINS are not sufficient to continue development at the level needed. The current level of personnel and equipment devoted to BlueSky and the user interface (RAINS or other) may not be sufficient to support ongoing regional or national research and development. Nor is it sufficient to support training on the BlueSky science application.

  BlueSky is at present a research application. We do not recommend that research funding be diverted to deploying it prematurely as a national centralized operational system, as this action would endanger the ability to complete development of the BlueSky system and make needed improvements. The current bootstrap approach to BlueSky research and development, with multiple funding sources tied to specific outcomes, may not be optimal either. We recommend a well-conceived development and deployment strategy built on a foundation of users' needs. This strategy would include, of course, a long-term financial commitment for research, systems design and development, and any future operational deployment.

Recommendations:

- **Maintain current BlueSky framework growth at the regional FCAMMS scale.**

  Focus research funding on the completion of research and development work,with operational aspects limited to ongoing testing and gathering of user requirements through the existing FCAMMS sites. Do not operationally deploy BlueSky nationally in a centralized fashion until its accuracy has been improved, it has been better evaluated by its potential users, it has met USDA requirements for life-cycle management, and the scientific and technological deficiencies of the current version are resolved.

- **Develop a stable, multiyear funding stream.**

  We recommend that the Department of the Interior, USDA, and EPA make a formal commitment to provide resources to complete research and development activities. Ideally this relationship would be formalized through an interagency agreement (or other such structure) that outlines responsibilities, tasks, products, and outcomes. We recommend that a formal National BlueSky Advisory Group be developed to define the next steps and funding needs. We further recommend that a formal funding target be developed and a commitment made for fiscal year 2007. It is not unreasonable to expect that funding for BlueSky development may be over $1.5 million annually for a period of 5 years.

- **Establish a formal life-cycle management project structure for BlueSky.**
  This project may need an interagency structure, depending on the level of commitment of people and funds by agencies other than the USDA Forest Service. Comply with departmental guidelines on life-cycle management, to meet the needs of both users and decisionmakers.

5. Conclusions

Major conclusions of the BSRW demonstration project were:

1. **Test operations and reliability.** BlueSky was found to be operable and reliable for the demonstration project. It is the best modeling framework available for wildland fire smoke predictions at this time, but it is still a research tool and needs further development. Further development, long-term planning, and support are needed before it can be considered operational. Additional development work is needed to improve its accuracy if BlueSky is to be used as a guidance or a regulatory tool.
2. **Model performance and evaluation.** BlueSky smoke predictions are difficult to evaluate in the field unless significant resources (e.g., money, equipment, and people) and forethought are applied. Although last summer's evaluation was not conclusive, it indicates that correlation between predictions and measurements needs improvement. Performance goals need to be developed for each potential application ranging from general information to guidance or even regulatory use.
3. **User needs.** In general, users support the need for a smoke modeling system and like the fire weather information produced ancillary to the smoke predictions. However, BlueSky smoke predictions have limited application owing to limited exposure and training opportunity as well as a perceived lack of confidence in the system's performance. Users have divided opinions on the GIS-based RAINS display system, with some users enthusiastic about the maps produced and others frustrated by the system's complexity. More time and effort is needed to develop a national user community for BlueSky.
4. **Future growth.** BlueSkyRAINS is not ready for implementation at one central location nationally at this time. For the immediate future, it would be better to implement BlueSkyRAINS regionally through the FCAMMS structure.
5. **Funding.** At present, the development of BlueSky is funded by USDA Forest Service with supplemental funds secured through competitive grants (JFSP, other). To continue development of this comprehensive system designed to meet various needs in the fire and air quality management communities, multiyear interagency funding commitments will be necessary.

Acknowledgments

Dr. Sue Ferguson, 1953-2005

This project is dedicated to Dr. Sue Ferguson who passed away as it neared completion. Sue Ferguson was the lead Principal Investigator of the BlueSky Smoke Modeling Framework, and founder of the USDA Forest Service Pacific Northwest Research Station's AirFIRE Team. This project would not have been possible without her scientific vision, energy, and enthusiasm. She was and is still the foundation upon which BlueSkyRAINS is built.

Figure 3—Sue Ferguson

Appendix A—December 2004 WFLC Briefing

National Fire Plan

WILDLAND FIRE LEADERSHIP COUNCIL

December 6, 2004

Topic: BlueSkyRAINS Smoke Modeling System Western States Demonstration Project

Issue: Whether to fund a one-year project to demonstrate the feasibility and usefulness of an advanced wildfire smoke modeling system for the western states (BSR WEST).

Key Points:

- In June 2004 **EPA Administrator** Leavitt saw the USDA FS/EPA BlueSkyRAINS (BSR) smoke system demonstrated, decided that it would be very useful for determining smoke impacts from wildfires, and **directed his office** to work with FS, DOI bureaus, NASA, NOAA, and Department of Homeland Security **to test and implement BSR** in the western states *for wildfires and wildland use fires only* **within 90 days**.
- **BlueSky is a smoke modeling frame work,** consisting of multiple large computer models, that is now run by PNW Research Station for Oregon, Washington, and parts of Idaho and Montana. **RAINS is a GIS application** developed by FS R&D and EPA Region 10, that is used to display the smoke model outputs against cities, schools, roads, political boundaries. **BSR is a combination** of the two, **whose** fire data comes from ICS 209 reports (wildfires and wildland use fires) and the PNW FASTRACS. From such information **smoke trajectories, ground level concentrations, and other information are** calculated and **available to users via the internet**.
- **BSR WEST** would begin **coverage of all western states** using data already automated in 209 reports (thus not addressing prescribed fires due to lack of automated activity data). The demonstration would proceed for a one-year period **with FS R&D (PNW and RMRS stations) running the system**.
- **During** the **one-year demonstration** we would hope to **learn**:
    - **How accurate** the system is in other terrain/ecosystem types
    - How **state air agencies** and **fire managers view** the **system** and it's **usefulness**
    - Whether the system **can aid prescribed fire** scheduling/**permitting** west-wide
    - If the system **can be scaled-up to** cover the **entire United States**
    - **How** the technology, **if proven**, might be **implemented operationally**

- The **BSR WEST** one-year **demonstration will cost $360,000.** It will build upon existing investments by FS R&D from base funding **and** from funds under the research portion of the National Fire plan. The **project will be managed by FS R&D** with oversight by FS Fire & Aviation Management and US DOI. It is recommended the **funding** for this demonstration be **shared between USDA Forest Service, US DOI and EPA**.

Appendix B—Operations Team Report

B.1. Team Purpose and Objectives

The operations team was responsible for all activity associated with creation, visualization, and delivery of the daily experimental smoke concentration forecasts from the BlueSky system. The BlueSky system contains multiple components, including both a smoke modeling framework and a variety of visualization tools, notably the BlueSkyRAINS ArcIMS Web interface. The operations team was specifically responsible for the setup, daily operations, and maintenance of these systems, including data archiving and delivery. Because the BlueSky system requires the use of meteorological forecast data, the operations team was also responsible for daily real-time production of MM5 forecasts for the Westwide domain.

B.2. Background

The BlueSky smoke modeling framework was developed by the USDA Forest Service Pacific Northwest (PNW) Research Station's AirFIRE Team through a grant from the National Fire Plan. The RAINS ArcIMS Web interface was originally developed by the Environmental Protection Agency (EPA) and was heavily modified by the EPA and USDA Forest Service in order to combine it with the BlueSky smoke modeling framework into the BlueSkyRAINS system.

The BlueSky smoke modeling framework is a collection of fuel, fire, consumption, emissions, atmospheric, and dispersion models. For input, BlueSky requires numeric weather predictions on a grid, typically from the MM5 mesoscale atmospheric model. The MM5 model takes more global forecasts (e.g., from the US NOAA ETA model) and regionalizes them by using a fine-scale grid (12 km) for this analysis. Finer grid scales are available for different areas within the study domain.

BlueSky also requires fire information (location and size) for the fires that will be modeled. Additional data such as fuel loadings may be provided but are not required. The BlueSky smoke modeling framework further requires domain-specific geographic information to be supplied at setup so that it can correctly geo-reference the models to the landscape. BlueSky runs under the UNIX/LINUX operating system and includes software code written in C, C++, PERL, FORTRAN that rely on publicly available libraries. Compilation of component models on the computer is required before use.

The RAINS system, as implemented in BlueSkyRAINS, uses the ArcSDE database and the ArcIMS geographic information system (GIS) Web server, both of which are licensed software from the ESRI Corporation. RAINS requires the use of a variety of GIS-based layers representing features of the particular domain, such as terrain, roads, rivers, and urban centers. BlueSkyRAINS requires enabling of software routines for transferring data from the BlueSky model output into the RAINS ArcSDE database.

B.3. Methodology

The operations team was responsible for implementing BlueSkyRAINS over the entire coterminous Western United States. Primary responsibility for this work was undertaken by the USDA Forest Service Rocky Mountain Research Station, Rocky Mountain Center (RMC); the USDA Forest Service AirFIRE

Team; and the EPA. The RMC and AirFIRE Team are participants in the Fire Consortia for the Advanced Modeling of Meteorology and Smoke (FCAMMS).

The setup decided on was:

- 48-hour forecasts starting at 0600 and 1800 daily.
- Standard MM5 configuration including 41 vertical layers and a 12-km grid to be produced at the RMC. A secondary 36-km MM5 grid was made available as backup by the Northwest Regional Modeling Consortium (NWRMC) (see table 3).
- BlueSky smoke modeling framework to be run at RMC for 12-km resolution BlueSky output fields, with help setting up from AirFIRE.
- Automated ingestion of wildfire and wildland fire use data from national ICS-209 reports.
- Fuel Characteristic Classification System (FCCS) fuel loadings as defaults.
- Fuel consumption and heat release was calculated by using the EPM/CONSUME models
- RAINS implemented in a way similar to the Northwest prototype by the EPA, with help from AirFIRE.

This setup was an ambitious one. The 12-km-grid spacing choice was made because studies had indicated this scale was optimal for use, but it generated an extremely large grid. Implementing the 12-km grid across the Western United States required modifications to the RAINS system database to accommodate the data.

Significant computer power was required to run MM5 for this grid, and the power was supplied by a LINUX/Beowulf cluster at the RMC, one of a new generation of low-cost, high-performance computing clusters that have the throughput previously only available in supercomputers. High-speed Internet connectivity was required to pull and push gigabytes of data daily, fast enough to provide real-time predictions. A high-performance Web server and a Windows-based computer with ArcSDE and fast-disk access were used to reduce response delays; these two computers were provided by the EPA.

The major work items for setup of this implementation were:

- Implement the MM5 forecasts for the 12-km Westwide grid (RMC).
- Implement BlueSky for the 12-km grid (RMC and AirFIRE).
- Set up a new RAINS server at EPA and modify RAINS for the 12-km grid (EPA).

After implementation, the major ongoing tasks were:

- Daily maintenance (RMC, AirFIRE, EPA).
- Quality control (RMC, AirFIRE).
- Data archiving (RMC, AirFIRE, EPA).

B.4. Activity/Work Done

The work items for implementation were completed and were functioning by mid-May for the Western wildfire season, with the implementation of RAINS delayed until August.

By mid-May, the meteorological simulations and the entire BlueSky framework were operating as planned at RMC. Users were able to access wildfire smoke data and information at the RMC Web site (www.fireweather.info). Display of the data products was limited to static and animated graphics interchange format (GIF) files. Users were given an option of manually entering prescribed fires into the system and having the smoke from such prescribed fires simulated along with smoke from wildfires. Work on this goal was accomplished by RMC and AirFIRE staff.

Implementation of the RAINS system was contracted out by EPA to the Computer Science Corporation, which employed Ray Peterson, one of the founders of the RAINS system. Work was delayed while the contract was put in place. The contract was effective in early August, and within 3 weeks the EPA brought the RAINS system online using the daily RMC product.

Both the BlueSky and RAINS components were modified throughout this effort to fix problems and make the systems more robust. Although all operations requirements were met by August 2005 (later than first anticipated), the system went through continual improvements throughout the demonstration project period. The entire system was shut down in mid-January 2006.

B.5. Major Accomplishments

The following are major successes of the project:

- The BlueSkyRAINS system was operated for a high-resolution (12-km) grid over the largest geographic domain ever attempted (coterminous Western United States).
- BlueSky was operated for most of the wildfire season in the Western States, with steady improvements made to the model during the demonstration period.
- The RAINS system was operational for the entire Western States domain and has also been significantly improved as a result.
- Web capability for user input and critique was developed at RMC during the demonstration, perhaps an obvious step, but one that had not been done before.
- New and useful technical partnerships were formed among the FCAMMS, EPA technical specialists, and the Department of the Interior.

B.6. Major Challenges

Major challenges included:

- Although BlueSky was operational at RMC and AirFIRE by mid-May, the entire BlueSkyRAINS system was not operational for all Western States by April as originally planned, and thus much of the wildfire season was missed.
- The ICS-209 reports are not a sufficiently accurate source of fire information for smoke prediction, and they did not improve during the demonstration period.
- Other than New Mexico state smoke specialists, users remained almost completely unaware of the demonstration project, and although the system did operate, very little user awareness of BlueSkyRAINS was achieved beyond that which already existed.
- Uncertainty remains about BlueSkyRAINS and its capabilities as a technical tool, both as to its functionality and whether or not it can be made a fully operational tool.

B.7. Conclusions

Technical (computing):

a. **Critical for successful implementation:** Neither BlueSky nor RAINS are simple applications. Neither is completely technically evolved or ready for large-scale release, in the sense of being stable and of verified technical capability in all aspects. However, both are useful as evaluation tools while their development continues. For each to operate routinely, significant technical and scientific support capabilities are needed.

b. **Nice to have—in the future:** For BlueSkyRAINS to operate reliably, it needs a significant and stable computer capacity with appropriate redundancy. A functional system will also need technical personnel operating with appropriate scientific supervision.

Technical (science):

a. **Critical for successful implementation:** System evaluation of the BlueSky modeling framework is necessary before it is defensible as a regulatory tool or even as a smoke-impact evaluation tool.

b. **Nice to have—in the future:** There is also a need for a reliable vegetative cover and a national fuels database that is sufficiently accurate and precise for the calculation of fire emissions. Landfire is a definite candidate for this, but its usability to calculate fire emissions needs to be demonstrated. The national FCCS fuel load mapping provided by the USDA Forest Service Fire and Environmental Research Applications team has already greatly improved the vegetation and emission information. Other research is also needed, such as investigation into alternative emissions models and dispersion models, linkages with fire behavior models, and research into statistical methods of model evaluation and application of satellite data.

Management:

a. **Critical for successful implementation:** The operation of the system will need to be funded annually on a sustained basis. Because the system is still a research application and not fully developed, it will need close scientific supervision and linkage to the ongoing research program. Clear direction and development goals from an interagency steering committee may also be critical to the future success of the project to ensure that limited resources are focused on key issues.

b. **Nice to have—in the future:** Ultimately, a fully operational version of BlueSkyRAINS is needed. Improved input fire activity data is important to fully exploit the potential of the BlueSky program. The accuracy of ICS-209 reports needs to be improved as well as developing a facility for capturing large-scale burn-out activities. There is also a critical need for automated and accurate reporting of both planned and actually executed prescribed fires with enough information to allow reasonable estimates of fire emissions.

B.8. Recommendations

Technical:

- Continue the development of BlueSkyRAINS within the FCAMMS framework for the next several fire seasons, with increased emphasis on user evaluations of the system.
- Expand the automated BlueSkyRAINS evaluation project (funded by the Joint Fire Science Program and conducted by the PNW Research Station AirFIRE team) to include all Western States. Integrate developments from the National Aeronautics and Space Administration (NASA)-funded decision support system (DSS) project into the operational BlueSkyRAINS system. A major component of the NASA project involves using NASA products such as satellite data to initialize and evaluate the BlueSkyRAINS smoke predictions.
- Improve RAINS system performance for these large data sets and consider consolidation of RAINS.
- Perform a series of calibration field experiments to optimize model/ground observation performance.

Management:

- Determine the need for smoke simulation modeling in support of fuels treatment and management.
- Develop methods, which might include a national data system, for collection of fire activity data useful for calculating fire emissions.
- Improve user evaluations of the system.

Table 3—Technical details of the meteorological model (MM5) and the configuration and settings used in the BSRW demonstration project

Model version:	MM5 Version 3.6.3
Horizontal grid:	448x448 12-km grid
Vertical levels:	41 levels
Lowest model level:	~25 m
Initialization time:	0600Z and 1800Z; ATMET, Inc. LAPS Analysis (6-km grid)
Δ T:	18 seconds
Model physics:	Reisner mixed phase including graupel (Reisner2) microphysics
PBL scheme:	MRF
Radiation:	RRTM scheme (longwave), cloud-radiation scheme (shortwave)
Surface scheme:	NOAH Land-Surface Model
Boundary conditions:	NCEP Eta forecast (6-hr interval)
Cu-parameterization:	None

Appendix C—Data Collection Team Report

C.1. Team Purpose and Objectives

The data collection team was responsible for gathering the field observations necessary to characterize model performance during the demonstration project. This work included conducting two field campaigns, as well as gathering data from existing monitoring networks. The necessary data were identified and gathered in consultation with the data analysis team.

C.2. Background

The BlueSky smoke modeling framework contains many different kinds of models linked together to produce smoke concentration and trajectory predictions. Thorough evaluation of model predictions requires numerous realizations to encompass the range of possible conditions (weather, topography, fuels). Specifically designed field observation studies can attempt to isolate specific model processes and evaluate their effectiveness, but generally a large number of realizations are needed.

One of the major data collection activities involved measuring ground-smoke concentrations of PM 2.5, which was done by using a variety of instruments (903 nephelometers; E-SAMPLERs, devices for measuring airborne particulate; and E-BAMS, portable air-sampling machines). These instruments measure particulate matter concentrations through a variety of indirect techniques.

C.3. Methodology and Activity/Work Done

The goal of the data collection team was to obtain two field studies with enough instrumentation that the data analysis team could evaluate, in part, the effectiveness of BlueSky. A secondary goal was to collect enough data in each field study so that specific models or model processes could be determined to be the likely weakest link, and therefore in need of further development. To supplement the field observations, we also obtained data from existing ambient particulate monitors and satellites.

The two field experiments are described below.

First Experiment Description and Overview

The first experiment was carried out from June 27 to July 4, 2005, around the Bull Wildland Fire Use in the Gila National Forest, New Mexico. This fire was instrumented with different types of sensors located close to the actual fire. The sensors included light detection and ranging (LIDAR) and forward looking infrared (FLIR), as well as particulate monitors (903 nephelometers; E-BAMS, portable air-sampling machines; an E-SAMPLER device for measuring airborne particulate; and DataRams, another type of portable air-sampling monitor). The LIDAR was provided and staffed by the USDA Forest Service Rocky Mountain Station. The FLIR was provided by the fire chemistry research work unit of the Missoula Fire Laboratory. The smoke monitors were provided by the USDA Forest Service Pacific Northwest (PNW) Research Station and the national Forest Service cache maintained by Air Resource Specialists. Additional staffing was provided by the USDA Forest Service PNW Station, New Mexico Environment Department, and the Arizona Interagency Smoke Management Program. The monitoring effort was challenged by lack of power for monitoring equipment and equipment failures.

Second Experiment Description and Overview

The second field experiment was carried out from September 3 to 14, 2005, when 17 smoke monitors were placed in southeast Idaho and southwest Montana to measure smoke coming primarily from the Frank Church complex on the Salmon-Challis National Forest. The monitors were placed in a wide field array spanning roughly 97 km from east to west and 161 km from north to south. The monitors were provided by the USDA Forest Service PNW Research Station, Missoula Technology and Development Center (MTDC), and the national Forest Service cache maintained by Air Resource Specialists. Personnel were provided by the research branch and National Forest System.

The Frank Church complex was selected because of its potential for continued fire growth and its proximity to nearby towns that had the power needed for placement of the DataRam monitors. The goal was to place monitors at least 2 grid cells apart on the 12-km BlueSkyRAINS West model grid. Nine locations were at Forest Service offices along Highway I-93 at Hamilton, Darby, Sula, North Fork, Salmon, Cobalt, Challis, Leador, and Wise River; five were placed at private residences in West Conner, May, Tendoy, Grant, and Jackson; one at a fire lookout on Lookout Mountain, and one at a national park, Big Hole Battle Field (see figure 4 below).

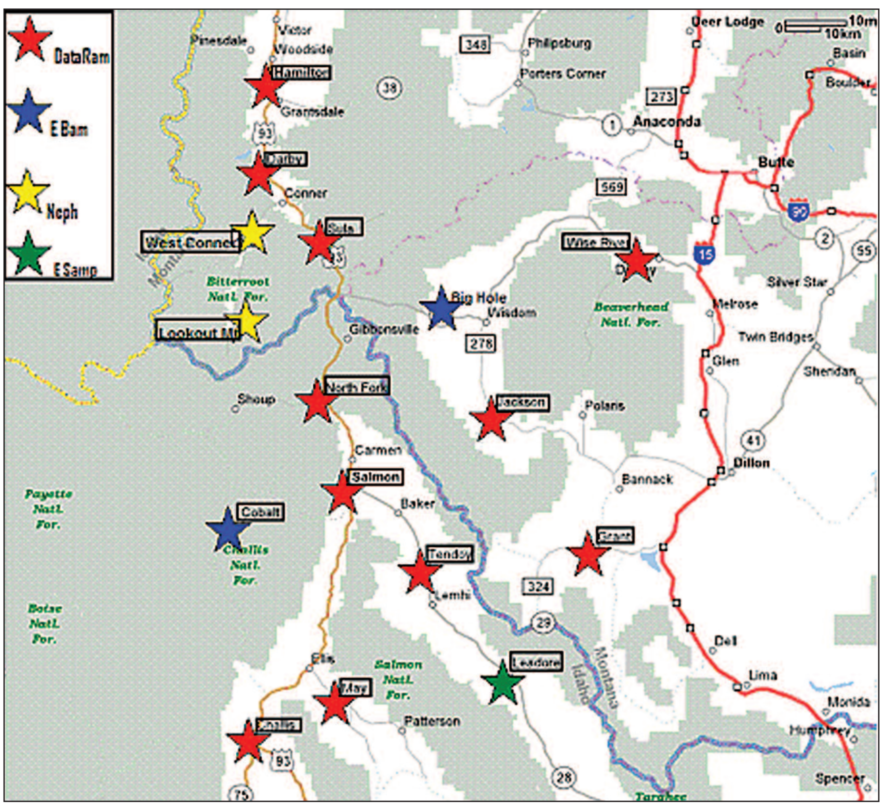

Figure 4—Instrument deployment. Deployed approximately 24 km (two 12-km grid cells) apart to avoid any duplicate grid-cell sampling.

Additional Data

Additional data were collected as available from state and federal fine-particulate, ambient monitoring networks across the West. Remotely sensed data were obtained from MODIS, GOES, and AVHRR satellite systems to provide fire detection, smoke plume, and optical depth measurements. The data collection team also coordinated with the operations team to collect and archive all of the weather and smoke model predictions for delivery to the data analysis team.

Data Availability

All data are available to the public by contacting Sim Larkin, USDA Forest Service PNW Research Station, larkin@fs.fed.us, 206-732-7849.

C.4. Major Accomplishments

The following are the major successes of the project:

- Quickly organizing and carrying out two field campaigns. Field campaigns are usually carried out with long lead-time planning, but we were able to carry out two studies rapidly with a team of cooperators and equipment from many agencies and locations.
- Design of the second field experiment. The data from the second field experiment have proved to be the most useful for the data analysis. In this experiment the focus was on using limited resources to gather more data from one type of sensor (in this case, ground concentrations) rather than to gather smaller amounts of data from different types of sensors.
- Education of fire management officers and air quality regulators in regions where the field experiments were done. The coordination efforts for the two field campaigns helped to disseminate information about BlueSky in those areas. The people contacted for the field experiments who were unfamiliar with BlueSky quickly became very interested in the BlueSky system and the data collection experiments.
- Multiagency collaboration on a field campaign.

C.5. Major Challenges

Major challenges of the data collection activities included:

- Field operations would have been improved with more preplanning and clearly defined objectives precluded by the need for rapid deployment. Contributing factors include late and uncertain availability of funding, inadequate funding for the field operations, unclear project goals, sporadic wildfire conditions for this type of monitoring, and the challenge of bringing together personnel and monitoring resources from virtually all over the country and a variety of different agencies and groups.
- Inadequate funding and resources for deployment.
- Identification and enlistment of qualified personnel to staff the field experiments.
- Distance from all of the research labs, and the need to transport significant quantities of the equipment to the sites.

- Travel times cutting into the effective measurement window as fire conditions progressed.
- Maintenance of the field equipment, especially after shipping.
- The need to rely on locations with available AC power.

C.6. Conclusions

Technical:

a. **Critical for successful implementation:** The DataRam smoke monitors need adequate shipping cases and padding if they are to be shipped to the field location. Better success was obtained by driving the monitors from the cache to the field location.

b. **Nice to have—in the future:** Calibrate all smoke monitors both before and after the deployment to minimize calibration and drift errors.

Management

a. **Critical for successful implementation:** Development of a monitoring plan with coordination with likely cooperating federal, state, local, and tribal air monitoring entities prior to fire season. Resources dedicated to identification of fires that may be successfully monitored to meet clear objectives will ensure a timely go/no-go decision to deploy.

b. **Nice to have—in the future:** To determine quickly if a fire is well suited for a field experiment, develop in advance a description of the background and a checklist of criteria that make a fire well suited for deployment (size, fuel, type, personnel to support, logistical needs, etc.), data collection needs, types, and an overall coordinator with single point of contact onsite.

C.7. Recommendations

Technical

- Conduct ground-based observational deployments of the type used in the Frank Church Fire. These field experiments will involve large-scale deployments of an array of smoke monitors for an extended period.
- In any future deployment, identify fires quickly by using specific standards.
- Future deployments may wish to focus on wildland-fire-use fires as they produce enough smoke to be measurable, yet are not subject to the management need to suppress the fire.
- Calibrate smoke monitors both before and after deployment.
- Obtain smoke monitors in advance of the deployment.
- If possible, obtain solar-power or battery systems so smoke monitor placement is not limited by power availability.
- Deploy monitors on site that are charged and ready for calibration.
- Transport monitors by deployment staff or provide adequate shipping cases to ensure a safe arrival.
- Proper training and/or prior experience with deploying specific instruments is key for success of deployment personnel.

Management

- Any future data collection activities need to have a clear plan including chain of command.
- Develop specific standards to identify fires for deployment to meet specific objectives in model performance or operation.
- Develop personnel lists well before any deployment.
- A key to success is coordination before the fire season with federal, state, local, and tribal air quality regulators in likely areas of deployment.

Appendix D—Data Analysis Team Report

D.1. Team Purpose and Objectives

The data analysis team was tasked with characterizing the performance of the BlueSky framework as implemented in the BlueSkyRAINS West demonstration project. This task was undertaken with the understanding that the time and resource limitations on the project would not allow for a rigorous, complete analysis. Instead, the goal was to provide a partial evaluation of the BlueSky system, find any obvious significant issues, and develop a set of recommendations on how to develop the system further.

D.2. Background

Model evaluations are complex studies designed to provide guidance on both the performance (output vs. reality) of the model, and on the realism of the underlying model-process parameterizations. Models that simulate large-scale natural systems are particularly hard to evaluate as the conditions under which the evaluation occurs cannot be controlled like laboratory experiments can. Thus many observations are needed to sample the range of possible conditions (e.g., weather, topography) under which the model is expected to perform.

BlueSky output currently relies on the following models:

- General circulation models for global weather system forecasting.
- MM5 mesoscale model for regional weather forecasting.
- National Fire Danger Rating System fuel moisture calculations based on weather forecasts.
- Fuel Characteristic Classification System (FCCS) fuel loadings where observational fuel loadings are not available.
- Simple fire-growth projections for wildfire growth, based on ICS-209 reports.
- CONSUME/EPM for fuel consumption and emissions predictions based on fire growth, fuel loadings, and weather.
- CalMet for preprocessing MM5 weather predictions for use in CalPUFF.
- A plume in grid calculation with plume-rise calculation based on fire heat and state of the weather.
- CalPUFF for dispersion of the plume (inserted by the plume in grid calculation) downwind and smoke concentration calculations.
- HySPLIT for smoke trajectory calculations.

Identification of specific model issues is difficult in such a complex environment. Typically, sensitivity studies are done to determine likely error propagation. Most of these models have been studied and evaluated individually, so many specific issues associated with these models have been previously identified by other studies.

D.3. Methodology

Because of the complexity of the BlueSky model framework, a two-pronged approach was taken. First, statistical analysis was done to compare the model output with available observations to determine the accuracy of the model predictions. Second, as a limited sensitivity analysis, several model runs were compared to each other and the observations to determine specific model issues and therefore areas to improve. The goal of the analyses is to provide insight into how specific variables (e.g., fuels, burn area, characterization, plume rise, meteorology) affect model performance (trajectories, dispersion, and ground-level concentration), and, as available, develop conclusions about the application of the modeling system and the factors limiting performance.

Observational data were gathered from the two field studies done for the demonstration project, ambient PM 2.5 monitoring data available through the AirNOW system, and state air monitoring systems. Actual fire growth and fuel loading information were gathered retrospectively from the appropriate fire management officers as available. Satellite data were also obtained: aerosol optical depth observations from the National Aeronautics and Space Administration (NASA) Earth Observing System Data Gateway, NESDIS analyst-interpreted visible smoke plume extents based on satellite observations from the National Oceanic & Atmospheric Administration (NOAA) Hazard Mapping System, moderate resolution imaging spectroradiometer (MODIS) fire locations, and burned area reflectance classifications from the Remote Sensing Applications Center. All observational data were aggregated and gridded onto the appropriate model grid for the analysis.

Model outputs were gathered from several different model runs. All of the meteorological (MM5) forecasts used for the BlueSkyRAINS model runs were gathered, as were all fire-size growth, and fuel loading input data. BlueSky forecasts were gathered from both the BlueSkyRAINS West system and the BlueSkyRAINS Pacific Northwest system. For the Pacific Northwest system, both the 12-km and 4-km forecasts were obtained. Also, a retrospective MM5 model run was done to provide actual meteorological information that incorporated all of the available observational data. Retrospective BlueSkyRAINS model runs were then done by using this retrospective meteorological data (see table 4).

Table 4—Model runs used

Type of run	MM5 data	BlueSkyRAINS (BSR)	Grid
Forecast	Forecast	BSR-West	12 km
		BSR-PNW	4 and 12 km
Retrospective	Hindcast with observational data	BSR-West	12 km
		BSR-PNW	12 km

D.4. Activities/Work Done

All of the observational and model data were placed into a geographic information system (GIS) data base for analysis. Most database construction and model/observation analyses was done by Sonoma Technologies, Inc.,[1] under guidance from the data analysis team. Additional analyses were done by the Environmental Protection Agency (EPA), Department of the Interior Fish and Wildlife Service, and USDA Forest Service Pacific Northwest (PNW) Research Station.

Model output/observation comparisons were done primarily for the time period of the second field experiment because the observational data gathered during that period proved most beneficial to the limited analysis done in this study. Model data and observational data were analyzed to:

- Determine spatial and temporal trends in the PM 2.5 data from air quality monitoring systems.
- Compute statistical estimates of the PM 2.5 concentration fields from the monitoring data.
- Compare spatial and temporal trends of PM 2.5 fields estimated from monitoring data with PM 2.5 fields simulated by the modeling system.

Standard statistical analyses were done to determine a variety of mean error, mean bias, and correlation measures.

D.5. Major Accomplishments

Note: Several general technical reports and scientific journal articles are currently being developed based on the work performed in this study. These reports will document accomplishments and conclusions in more detail.

Major accomplishments included:

- Establishment of a multiagency analysis group.
- Identification of several specific issues with the model.
- An additional look at model/observation performance.
- Comparison with satellite data.
- Comparison of BlueSkyRAINS West with BlueSkyRAINS Pacific Northwest.
- A “best-case” retrospective run incorporating all available observations.

D.6. Major Challenges

Major challenges included:

- Time and resources available to select and conduct field studies.
- Resources were not sufficient to conduct a traditional model evaluation.
- This analysis is an opportunistic exercise, not a traditional model evaluation.
- Contract procurement issues caused delays in the data analysis timeline.
- Database sizes (terabytes of data) and database transfer.
- The field experiments were in complex terrain—a notoriously hard-to-model area.

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[1] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

D.7. Conclusions

All conclusions presented here should be understood to be best professional judgments, and not rigorous in a scientific sense owing to the limitations of the analysis as discussed above. Summary conclusions from the data analysis team's analysis include:

- The BlueSkyRAINS plumes do not predict the significant smoke concentrations within the observation area for the Frank Church field study.
- BlueSkyRAINS seems likely to be underestimating near-field smoke concentrations and potentially overestimating far-field smoke concentrations.
- Small changes to fire size and plume rise do not fix the near-field/far-field issue.
- The model did significantly better at predicting the maximum concentration over the domain as opposed to a specific location.
- All of the BlueSkyRAINS systems tested showed an unrealistic collapse of the mixing height at the onset of nighttime. This result causes the BlueSkyRAINS system to show smoke concentrations at the ground spiking at about 2000 local time.
- The mixing-height issue may be related to the near-field/far-field issue.
- A better algorithm is needed for calculating growth in fire size.
- Fire information and availability issues are critical to the long-term model performance success of BlueSkyRAINS.
- The BlueSkyRAINS Pacific Northwest system did somewhat better than the BlueSkyRAINS West system, possibly because of the different fire reporting systems (i.e., input data) available to the BlueSkyRAINS Pacific Northwest system.
- BlueSkyRAINS did substantially better (qualitatively) in predicting the long-range smoke plume than it did in predicting the smoke concentrations closer to the fire.

D.8. Recommendations

Summary recommendations from the data analysis team's analysis include:

- Do not deploy BlueSkyRAINS as a fully endorsed product for fire management until the technical issues associated with plume rise, mixing height and MM5 have been addressed. In the meantime, clearly label this as an interim experimental product.
- Consider including advanced statistical or process-oriented fire-size growth prediction models such as BEHAVE or FARSITE.
- Develop a nationally consistent fire reporting system that can be accessed by all implementations of BlueSkyRAINS.
- An ongoing verification system such as the one being implemented in the Pacific Northwest should be part of the BlueSkyRAINS system.
- Substitute a smoke emissions model with calculated smoldering emissions (such as FEPS) for CONSUME/EPM.
- Continue sensitivity analyses to determine further model improvements.

Appendix E—User Needs Team Report

E.1. Team Purpose and Objectives

The user needs team was charged with gathering information from end users on the BlueSkyRAINS West demonstration system. We engaged in the following tasks:

- Collect and generate a list of general business needs related to the fire smoke and air quality relation, as identified by national program contacts within the USDA Forest Service, Department of the Interior, and EPA. Identify and document how the BlueSky system is, or could be, utilized to meet these program needs.
- Collect and document examples of individual experiences within the BlueSky user community. Identify specific business needs at the local and regional levels and determine how a centralized support system helps accomplish these goals. Collect information on how or what additional support is needed to meet program goals.
- Collect and document examples of the RAINS Web-based delivery subsystem and how that system addresses user program needs. Explore whether alternative delivery subsystems exist or could be modified to provide the BlueSky product.
- Generate an assessment of the usability factor currently provided and potentially provided by the BlueSky system.

E.2. Methodology

The user needs team developed a multistepped approach to collect user outreach information:

- Develop a small yet representative list of known BlueSkyRAINS users who have a broad spectrum of business needs, application experiences, and user technical abilities. This list established a focus group for outreach.
- Develop a basic user-experience survey and attach it to the BlueSkyRAINS Web site, for voluntary use. Responses were collected from the Web surveys and focus group members and interpreted.
- Develop an approach to contact and interview people from the focus group list, including establishment of interview methods and questions to be used. Methods were also established for documenting reaction and responses from the focus group.
- Develop methods for screening and interpreting reaction and responses from the data collection process.
- Interpret focus group surveys and respond to objectives outlined above.

E.3. Activity/Work Done

The user needs team used the methodology described above and a consensus process for decisionmaking.

The availability of real-time and archived BlueSky products and presentation for the focus group was determined. We contacted three distribution sites to verify product availability, including the geographic information system (GIS)-based RAINS presentations for the Pacific Northwest from the Pacific Northwest (PNW) Research Station and for the Western United States from Environmental Protection Agency (EPA), as well as a static graphics-based presentation from the Rocky Mountain Center (RMC). Where complete data sets were not available throughout summer 2005, steps were taken to backfill archived products.

We developed a simple user-response survey that was included on the BlueSky distribution sites. Filling out this initial questionnaire was voluntary for users, and questions were simple so that users could fill out the questionnaire quickly.

The user needs team developed a list of known users to establish a primary focus group. Users were selected because of their diverse affiliations with fire and air quality as well as differing levels of information needs. Prospective focus group members were contacted by phone and asked if they would participate.

Once the focus group was established, we e-mailed an invitation asking focus group members to visit one or more of the BlueSky distribution sites. We explained to participants that current and archived information was available. A total of about 30 people visited the Web site and responded; after their Web site visits, evaluators were asked to participate in the online survey. Survey responses were collected and distributed to user needs team members.

User needs team members developed a second questionnaire that formed the basis for the followup phone-call interviews. The second set of questions was more focused and was distributed to evaluators before one of our team members called them on the phone.

Four members of the user needs team conducted the telephone interviews, and they interviewed 14 people. Results from the telephone survey were distributed to team members for review, and a method was established for user needs members to interpret and grade survey results. These results are discussed in the following sections.

E.4. Major Successes

- The initial reaction to BlueSkyRAINS is often extremely positive and enthusiastic, especially in the Pacific Northwest where prescribed fire impacts are simulated.
- Users generally recognize a great potential for BlueSky to meet their business needs even if it does not currently do so.
- Some users consult BlueSky predictions on a daily basis even though it may not be a primary tool in their decisionmaking process.

E.5. Major Concerns

- The current assessment is based on a small sample of users. A significant and continuing effort would be needed to conduct a proper user-needs assessment for BlueSkyRAINS.
- During the demonstration project, use of BlueSkyRAINS West output products was limited.
- User knowledge of and confidence in the BlueSkyRAINS system is limited.

E.6. Conclusions

The conclusions below are based on 14 telephone interviews and 30 questionnaires filled out at the RMC Web site. Therefore, when considering the conclusions below, the reader should recognize that a very small sample of the potential BlueSkyRAINS user community had input and full operation of BlueSkyRAINS West operated for a short period during the 2005 wildfire season. The small group that did provide input were knowledgeable about the issues and can be considered a relevant and significant group of users.

- BlueSky and BlueSkyRAINS have the potential to be useful tools for smoke management.
- Without further development and improvements to the system, it is unlikely that this potential will be reached.
- Further user outreach and training is needed to build confidence in the system, increase awareness, and expand the user base.

E.7. Recommendations

- Develop an ongoing user needs assessment group for BlueSky at a broader level than just the Pacific Northwest.
- Strive to improve the understanding of potential users about the usefulness of BlueSky products to support fire and air quality management decisions.

Appendix F—Team Members

Special recognition should be given to the Pacific Northwest (PNW) Research Station AirFIRE team in general, which is the intellectual child of Dr. Susan Ferguson, whose scientific vision was the foundation for BlueSky. Additionally, as developers of the system, AirFIRE was called upon to coordinate nearly every aspect of the project. Special mention goes to Drs. Narasimhan Larkin, Robert Solomon, and Susan O'Neill for this effort.

The personnel at USDA Forest Service Rocky Mountain Center, Drs. Karl Zeller and Ned Nikolov among others, spent many hours beyond the call of normal duty to ensure that the system operated consistently, and they added much technical wizardry. Another person of special note is Mr. Ray Patterson, without whose expertise RAINS would not have operated across the West and who built upon conceptual insights by Rob Wilson and Jon Schweiss of Environmental Protection Agency (EPA) Region 10.

Collection of field trial data was accomplished through the particular efforts of Candace Krull, Peter Lahm, Tom Pace, Charlene Spells, Tim Allen, and Rich Fisher. User needs were assessed through the efforts of Tim Allen, Dennis Haddow, Jeanne Hoadley, Donna Lamb, Sharon Nizich, and others. Finally, the difficult task of interagency coordination was accomplished by Dr. Sam Foster, Mary McCaffery, Sally Shaver, Robin Dunkins, Jim Douglas, and Dr. Deanna Stouder. Technical writing and editing was provided by Valerie Rapp, PNW Research Station.

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